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Characterization of the Test Section Walls at the 14- by 22-Foot Subsonic Tunnel

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October 2003

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Abstract

The test section walls of the NASA Langley Research Center 14- by 22-Foot Subsonic Tunnel are known to move under thermal and pressure loads. Videogrammetry was used to measure wall motion during the summer of 2002. In addition, a laser distancemeter was used to measure the relative distance between the test section walls at a single point. Distancemeter and videogrammetry results were consistent. Data were analyzed as a function of temperature and pressure to determine their effects on wall motion. Data were collected between 50 and 100°F, 0 and 0.315 Mach, and dynamic pressures of 0 and 120 psf. The overall motion of each wall was found to be less than 0.25 in. and less than facility personnel anticipated. The results show how motion depends on the temperature and pressure inside the test section as well as the position of the boundary layer vane. The repeatability of the measurements was ±0.06 in. This report describes the methods used to record the motion of the test section walls and the results of the data analysis. Future facility plans include the development of a suitable wall restraint system and the determination of the effects of the wall motion on tunnel calibration.

Introduction

Accurate measurements of wind tunnel models are essential in understanding aerodynamic performance. Subtle changes in tunnel airflow can affect the accuracy of a measurement. At the Langley 14- by 22-Foot Subsonic Tunnel (ref. 1), the two test section walls are known to move under thermal and pressure loads. According to facility personnel, previous measurements indicated the wall motion is less than 1 in., but the effect of the motion on the facility's structure and the tunnel calibration is unknown. Facility personnel are interested in restraining the walls but require a clearer definition of the effects under thermal and pressure loads and of the range of motion prior to designing a solution. This requirement exists because the design will depend on how much the walls are moving. Personnel are interested in understanding the wall motion to determine the effect on the tunnel calibration and if any corrections are needed.

A wall measurement test was performed using two videogrammetric measurement systems to characterize the motion of both test section walls and to correlate those results with the tunnel parameters to determine the thermal and pressure effects. The systems were used to simultaneously measure both test section walls to determine the magnitude, direction, and repeatability of the motion. Measurements were taken from April 17 to May 24, 2002, during the tunnel's calibration. In addition to the videogrammetric systems, a commercial portable laser distancemeter was used to measure the distance between the two walls at a single point.

Facility

The Langley 14- by 22-Foot Subsonic Tunnel is an atmospheric, closed return tunnel with a test section 14.5 ft high, 21.75 ft wide, and 50 ft long that can reach a velocity of 348 ft/s with a dynamic pressure of 144 psf. The Reynolds number per foot ranges from 0 to 2.2×10^6. The flow in the closed test section configuration is relatively uniform with a velocity fluctuation of 0.1 percent or less. When the test section is not in the fully closed configuration, the test section velocity is lower and the turbulence level is higher. Test section airflow is produced by a 40-ft diameter, 9-bladed fan powered by a 6650-hp alternating-current induction motor in tandem with a 1350-hp direct current motor. The tunnel has a set of flow control vanes to maintain close control of the speed for low-speed testing (ref. 2).

The facility has two main configurations, the open and closed test sections, and figure 1 shows an inside view of the closed test section. In the open test section, the walls and ceiling are raised creating an open test area where the flow is not restricted. The open test section is used for testing free flight and rotorcraft models. The flow is funneled back into the tunnel circuit with three flow collectors, which are large metal barriers brought together to make a funnel shape. For the closed test section, the flow collectors are pushed back, secured into position, and the test section walls and ceiling are lowered. Both test section walls are 50 ft long and 14 ft high. Each wall has three main columns that are tapered at the bottom to fit into mounting holes in the concrete floor. The three columns are supported at the top with trusses. Once the walls are in place, they are pinned at the floor and are thought to have little or no forward and aft motion. However, the front sections of the walls are neither supported at the top nor pinned at the bottom and are thought to move in as the tunnel is brought on line and move out as the temperature in the tunnel increases.

Measurement Systems

A nonintrusive videogrammetric measurement system was used to measure the motion of reflective targets attached to the test section walls. A separate videogrammetric measurement system, or VMS, was used to measure each test section wall. The VMS is a two-camera version of the videogrammetric model deformation (VMD) measurement system (refs. 3, 4, and 5). These systems use off-the-shelf components and a target-tracking software program developed in-house that automatically locates and identifies targets on wind tunnel models for aerodynamic measurements such as attitude and deformation. The program acquires 30 images per second from a camera, identifies all targets within the images, and computes the X-Y-Z coordinates for each target. Wind tunnel parameters, such as temperature and pressure, can be received from the tunnel's data acquisition system (DAS) via a network connection and saved along with the target data. Applications for videogrammetry include measurements of model deformation, wing twist, flap angle, and now large structure motion.

VMS Equipment Configuration

For the wall motion measurement test, two videogrammetric measurement systems were placed in the test area outside the test section. One system was set up to record the motion of the north test section wall while the other system recorded the motion of the south wall. The same equipment, calibration procedure, target arrangement, and program settings were used to configure each system. The equipment used is listed in table 1. The computers were located in the control room. The cameras and other equipment were mounted on the tunnel's flow collectors. Figure 2 shows the locations of two cameras, light sources, and power supplies on the north flow collector. The configuration was repeated on the south flow collector. A close-up of a camera and light source on the bottom of the south flow collector is shown in figure 3. The cameras were able to view over half of the wall without restricting access to the test section. A 12.5-mm lens was attached to each camera to obtain the best view. Twelve 2 in. round targets were placed on each wall. Figures 4 and 5 show the target layout on the outside of the north and south test section walls and the X-Y-Z coordinate system. The targets consisted of retroreflective tape and were placed in the locations indicated in the figures. For target numbers 7 and 8, 4-in. squares were used to ensure that the cameras could view them. Targets 10, 11, and 12 are on the front of the walls where the flow enters the test section. All of the camera images were fed back to the computers in the control room using RG-59 coaxial cable. Each system was calibrated and configured to match the tunnel's X-Y-Z coordinate system with the positive X-axis along the flow and the positive Z-axis vertical with the positive Y-axis forming a right hand coordinate system. Figure 6 is a screen capture showing the two camera images and the wind tunnel conditions window. The program was configured to record the tunnel parameters that are listed in table 2. To match the tunnel's data collection, the program was set to collect 8 s worth of data for each data point. An external trigger pulse was used to synchronize the data collection of the VMS and the tunnel's DAS. The VMS received a 5-volt pulse through a serial port on the computer allowing the system to operate autonomously. Data were collected at various times of the day and night during the tunnel's calibration test to determine temperature effects.

Portable Laser Distancemeter

Simultaneously with the VMS, a portable laser distancemeter was used to measure the relative distance between the test section walls at a single point. The distancemeter used was a DISTO™ pro^{4}a produced by Leica Geosystems (refs. 6 and 7) that has a typical measurement accuracy of ±0.06 in. and a range of 0.98 to 328 ft. The distancemeter uses a class 2 laser and is capable of being remotely operated from a computer via an RS-232 serial port using Lecia's DISTO™ online software. For the wall measurement, the distancemeter was attached to a light fixture on the outside of the south wall near the top, close to target number 6. Figure 7 is a top view diagram of the test area showing the test section walls and the location of the meter. This location put the meter at approximately 22 ft from the front of the wall and 10.5 ft up. The meter was aligned to measure straight across to the north wall. For the remote operation, the interface cable for the distancemeter was extended 75 ft to a computer located in the control room. The distancemeter was configured to automaticaly transfer a single measurement every 5 s once it was started. Measurements were recorded before, during, and after each tunnel run.

Summary of Results

The data provided by the VMS are in the form of X, Y, and Z values for each target. For this test, however, the main focus was on the motion of the walls in the Y direction, which is motion into or away from the test section. All data points were reduced to delta Y values in inches to indicate the displacement along the Y-axis from a reference point. The reference point was data point 858 recorded at a wind off condition. The delta Y values have a plus or minus sign to indicate the direction along the Y-axis. For the north wall, positive Y is to the right or into the test section. For the south wall, positive Y is also to the right but away from the test section. In this case, a positive delta Y for a north wall target and a negative delta Y for a south wall target would mean the two targets on each wall moved inward. Also in this summary, references will be made to individual targets and groups of targets to indicate a particular section of a wall. Looking at the target layout for either wall, targets 1 through 6 are in the midsection of the wall while targets 9 through 12 are in the front section. In the midsection, targets 3 and 6 are at the top and targets 2 and 5 are in the middle with targets 1 and 4 at the bottom.

Temperature

Table 3 shows how the temperature inside the test section affected the wall motion. The data points used in the table were between points 659 and 915 and were at the tunnel condition 120 Delta Pressure Indicated High Side or DPIHS. DPIHS is a measured value used to calculate Q, the dynamic pressure inside the test section. The mean target displacements along the Y-axis are from the wind off reference point. All data points fell within 70 and 80 °F or 90 and 101 °F with none between 80 and 90 °F. The column labeled "Diff." is the difference between the two means for each target. The differences show that the walls are moving as the temperature increases. For the north wall, the positive means and differences indicate the midsection moves inward as the temperature increases. The effect is the same on the south wall, which is shown by the negative numbers. The front section of each wall moves outward as the temperature increases.

Pressure

Figures 8, 9, and 10 show how the walls were affected by the pressure, or DPIHS. The data points used for the figures were between points

990 and 1125 and were within a temperature range of 85 to 101 °F. Each figure contains two graphs showing displacement data for each wall with the black data points for the north wall and the gray data points for the south wall. Figure 8 shows the effect on the top and middle of the midsection of each wall as pressure inside the test section increases from 0, or wind off, to 120 DPIHS. The data show the north wall moving in a positive Y direction and the south wall moving in a negative Y direction. This indicates an increase in DPIHS and causes the walls to move inward. The bottom of the midsection is moving inward as well but the displacement is definitely less, which is shown in figure 9. The pressure increase does not appear to affect the front section of the wall in the same way. Figure 10 shows the effect of pressure on the front section of each wall. The data show the front sections are not affected by DPIHS except for the south wall targets, 10 and 11, which indicates a slight outward movement.

Boundary Layer Position

The boundary layer position is a tunnel parameter that refers to the position of the boundary layer vane. The vane is a large butterfly valve used to draw off the boundary layer (ref. 1). The boundary layer position indicates the position of the vane from 0 percent, or suction off, up to 100 percent open, or suction on. Figures 11 and 12 show the effect of the boundary layer position on the midsection. The data in figure 11 show the top and middle of the midsections move inward more with the suction off than with suction on. In figures 12 and 13, the data show the bottom of the midsections and the front sections were not affected by the boundary layer position.

Repeatability

The wall motion data were analyzed for repeatability and the results are shown in table 4. The data points analyzed were at temperatures ranging between 72 and 76 °F, with all points at either wind off condition or at 120 DPIHS, 0 boundary layer condition. The numbers under the north wall and south wall columns are the standard deviation in inches from the reference point 858. The data show the wall motion repeated to within 0.06 in. in either direction along the Y-axis.

Comparison: VMS Versus Distancemeter

A comparison of the VMS data and the distancemeter data was studied for several test runs. All of the distancemeter data showed a decrease in the distance of the test section walls, indicating an inward wall motion, which agreed with the VMS data. For example, figure 14 shows the data set collected by the distancemeter during test run 204, which was a typical data set. The graph shows the wall to wall displacement over time as the tunnel went from 0.5 up to 120 DPIHS and then back to 0.5. The number labels inside the graph represent DPIHS. The picture inside the graph is an inside view of the test section with an illustration of where the measurement was made. The distance between the walls decreases as the pressure increases, and the distance decreased by 0.23 in. at 120 DPIHS, which is consistent with the VMS data. The VMS data shown in figure 15 are for target 6 during the same test run, 204. Target 6 was the closest target to the distancemeter and, at 120 DPIHS, the VMS recorded a displacement of +0.144 in. for the north wall and –0.073 in. for the south wall. Because both VMS readings indicate inward movement, the results are added for a total displacement of 0.217 in.

Concluding Remarks

Two videogrammetric measurement systems and a laser distancemeter were used to measure the motion of the two test section walls at the Langley 14- by 22-Foot Subsonic Tunnel. The overall motion of each wall was less than 0.25 in. and less than facility personnel anticipated. The motion is caused by changes in the temperature and pressure inside the test section and the position of the boundary layer vane. The mean repeatability was ±0.06 in. Future facility plans include the development of a suitable wall restraint system and the determination of the effects of the wall motion on tunnel calibration.

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6. Leica Geosystems web site: http://www.leica-geosystems.com Accessed August 6, 2003.

7. DISTO™ distancemeter web site: http://www.disto.com Accessed August 6, 2003.

Table 1. VMS Equipment List

Description	Model #	Quantity
Hitachi CCD camera	KP-M1U	2
12.5-mm camera lens		2
Fostec fiber optic light source		2
Panasonic video monitor	TR-990 C	2
Frame Grabber Matrox STD board	Meteor II	2
STD cable	STD-BNC-13	2
Interlink personal computer		1
NEC LCD1700V flat monitor		1
Power strip/surge protector		3
Hitachi AC adapter	AP-130U	2
Junction box		2
Hitachi camera cable	C-501KS	2
Coaxial cable	RG-59	4
3M Retroreflective tape		
Ames 54 target calibration plate		

Table 2. Wind Tunnel Parameters List

TEST	Test number
RUN	Run number
POINT	Point number
ID	Data point identification
DATE	Date
TIME	Time
MACH	Mach number
DPIHS	Delta Pressure Indicated High Side (used to calculate Q)
TA	Temperature inside the test section
PTOT	Total pressure
BLVIVPOS	Boundary layer guide vane position
VANEP	Downstream vane position
TWALLS	South wall skin temperature
TWALLP	Wall post temperature on the south side
TAIR	Outside air temperature

Table 3. Temperature Effects at 120 DPIHS

Target	Mean delta Y in inches for data points 659–915						
	North wall			South wall			
	70 to 80 °F	90 to 100 °F	Diff.	70 to 80 °F	90 to 100 °F	Diff.	
3	0.047	0.100	0.053	–0.040	–0.084	–0.044	Mid-section
6	0.054	0.078	0.024	–0.058	–0.077	–0.019	
2	0.038	0.113	0.076	–0.045	–0.085	–0.040	
5	0.059	0.093	0.034	–0.065	–0.092	–0.027	Moving inward
1	0.005	0.043	0.038	–0.032	–0.074	–0.042	
4	0.009	0.034	0.025	–0.037	–0.061	–0.024	
8	0.051	–0.003	–0.054	–0.070	0.021	0.091	Front section
7	0.031	–0.014	–0.045	–0.046	0.028	0.074	
9	0.103	0.016	–0.087	–0.074	–0.003	0.071	
11	0.160	–0.060	–0.220	0.099	0.300	0.201	Moving outward
10	0.179	–0.073	–0.252	–0.087	0.229	0.316	

Table 4. Repeatability Between 72 and 76 °F

Standard deviation at "Wind OFF"					
Target	Midsection		Target	Front section	
	North wall	South wall		North wall	South wall
3	0.016	0.007	8	0.016	0.017
6	0.013	0.007	7	0.015	0.023
2	0.011	0.005	9	0.032	0.015
5	0.016	0.006	10	0.021	0.023
1	0.009	0.004	11	0.015	0.065
4	0.016	0.007	12	0.026	0.062
Standard deviation at 120 DPIHS and 0 BL					
3	0.056	0.020	8	0.011	0.021
6	0.055	0.022	7	0.013	0.030
2	0.039	0.013	9	0.018	0.020
5	0.027	0.016	10	0.055	0.027
1	0.018	0.009	11	0.023	0.030
4	0.055	0.009	12	0.034	0.090

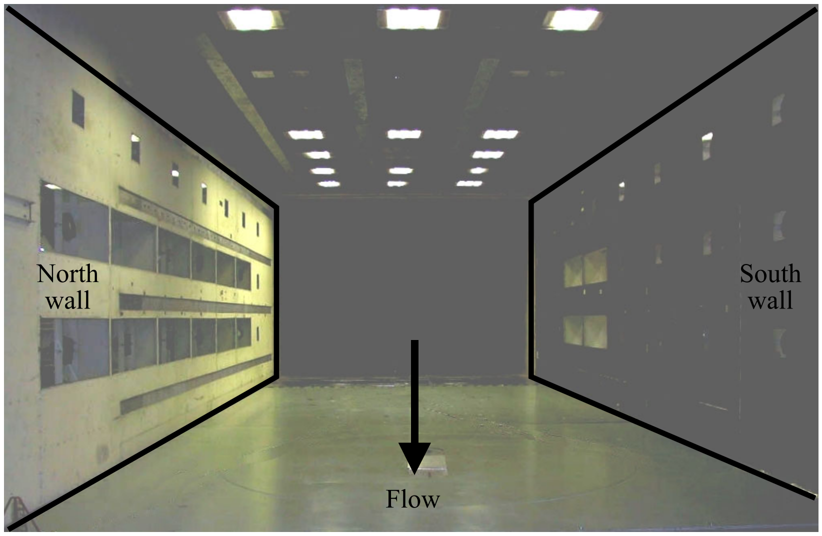

Figure 1. Inside view of test section.

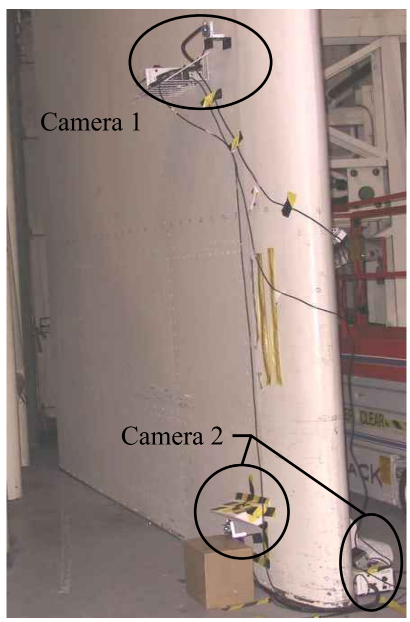

Figure 2. Equipment locations on north flow collector.

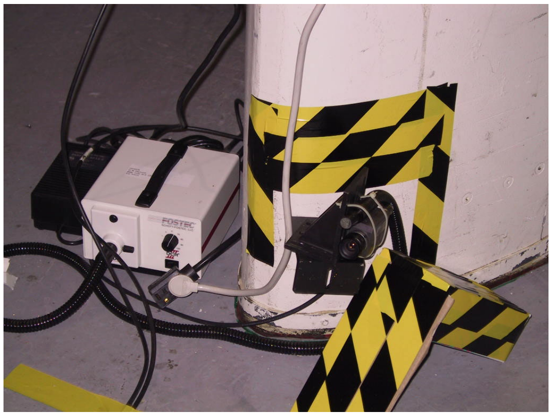

Figure 3. Close-up of camera mounts on south flow collector.

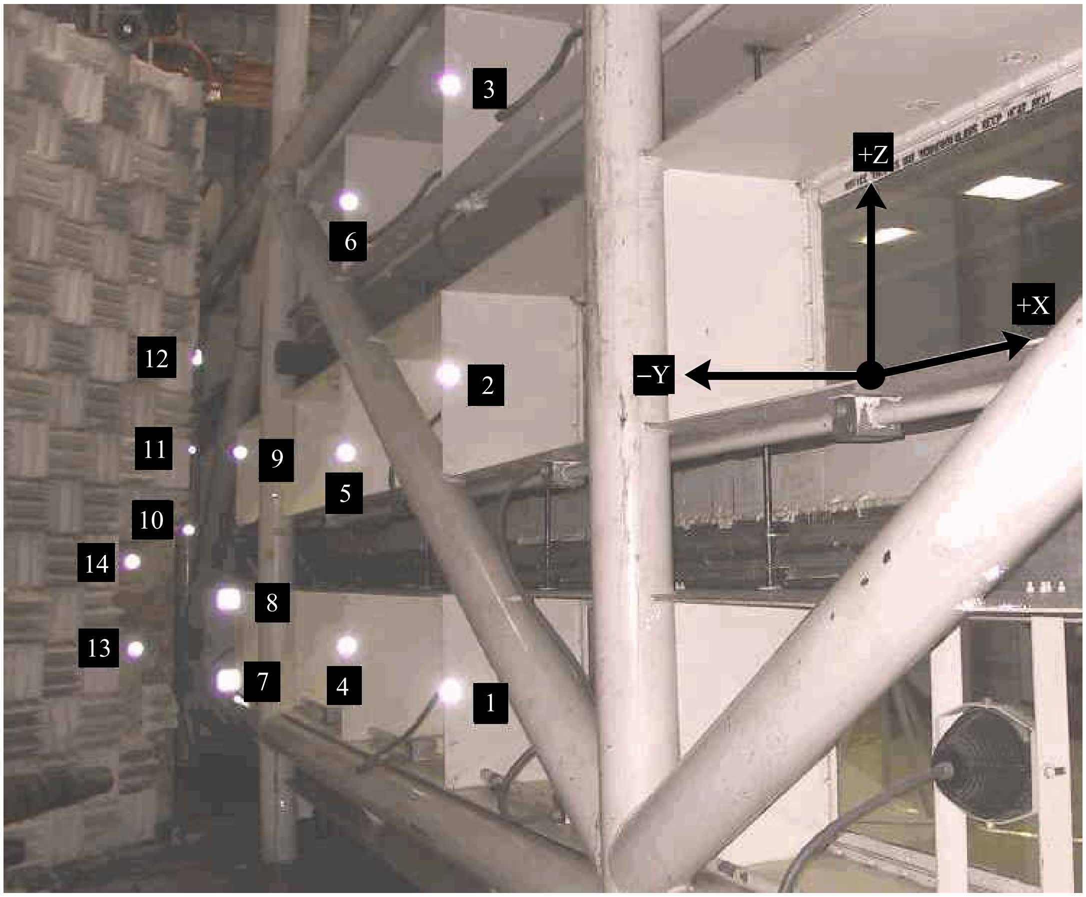

Figure 4. Target layout on north test section wall.

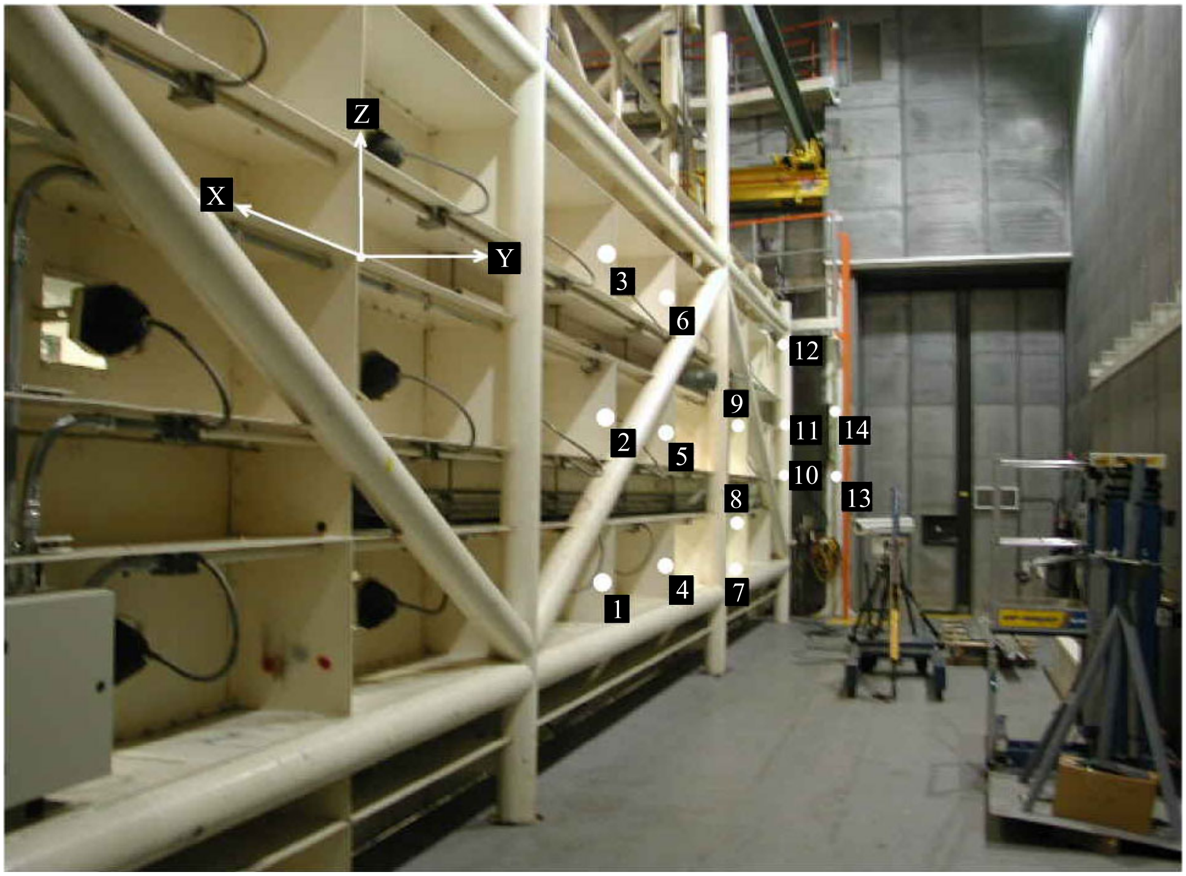

Figure 5. Target layout on south test section wall.

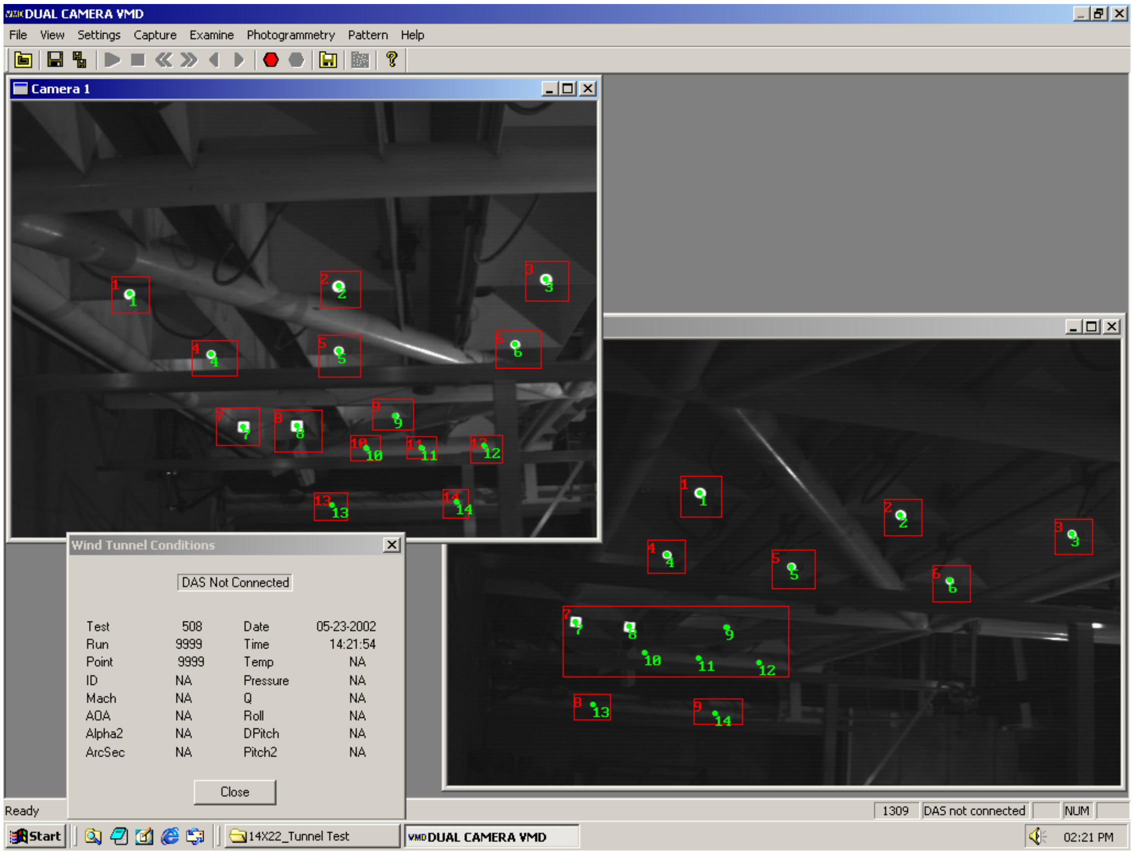

Figure 6. Screen capture of VMS program.

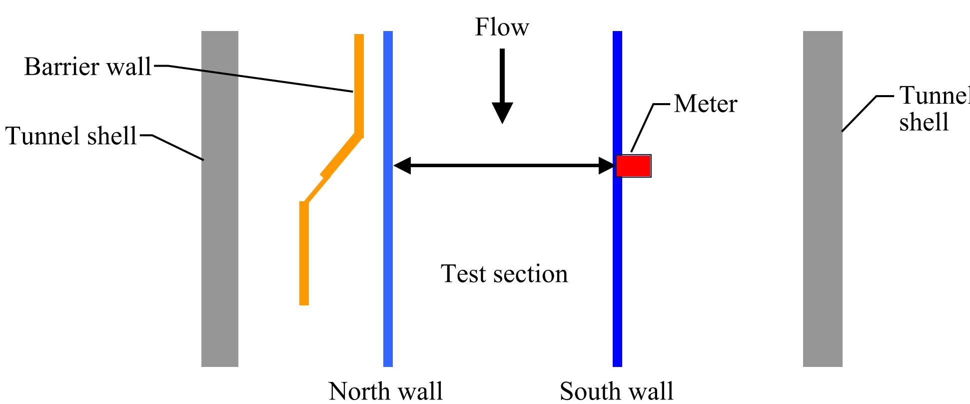

Figure 7. Top view diagram of test area.

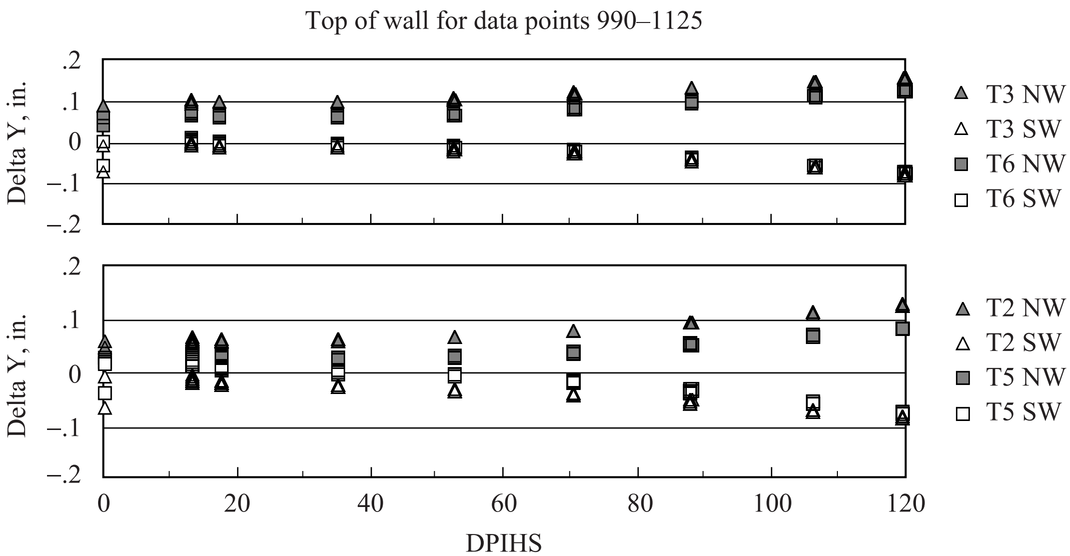

Figure 8. Pressure effects on midsection.

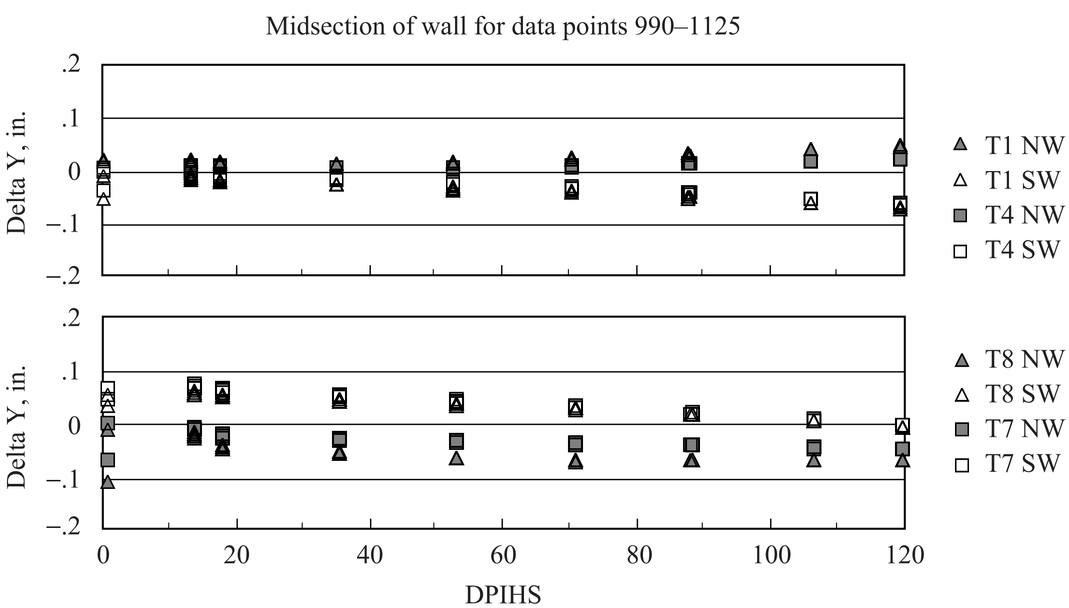

Figure 9. Pressure effects on bottom section.

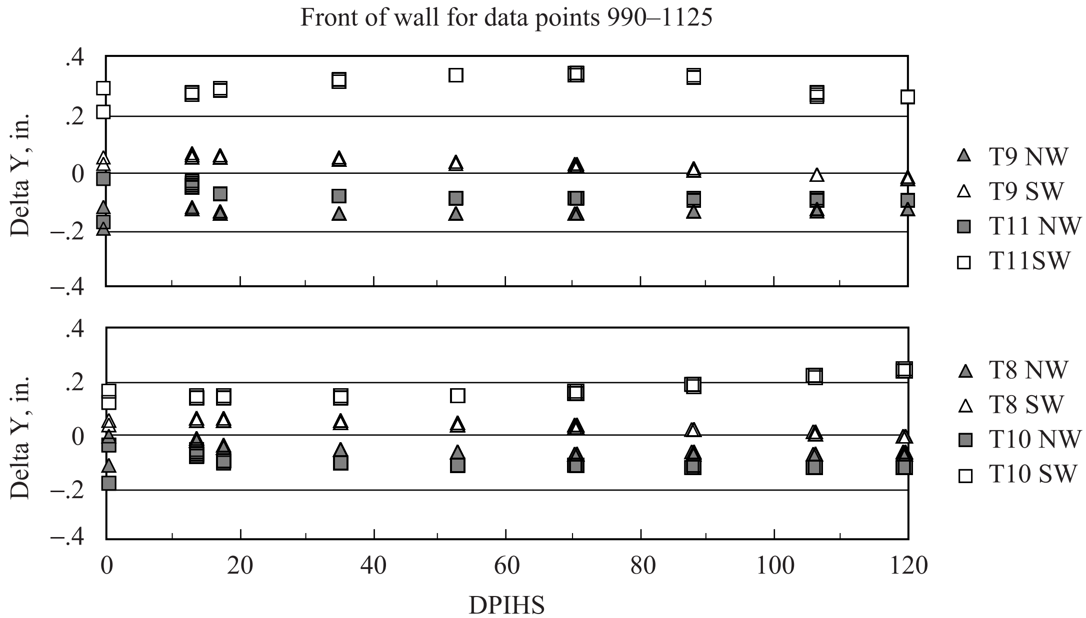

Figure 10. Pressure effects on front section.

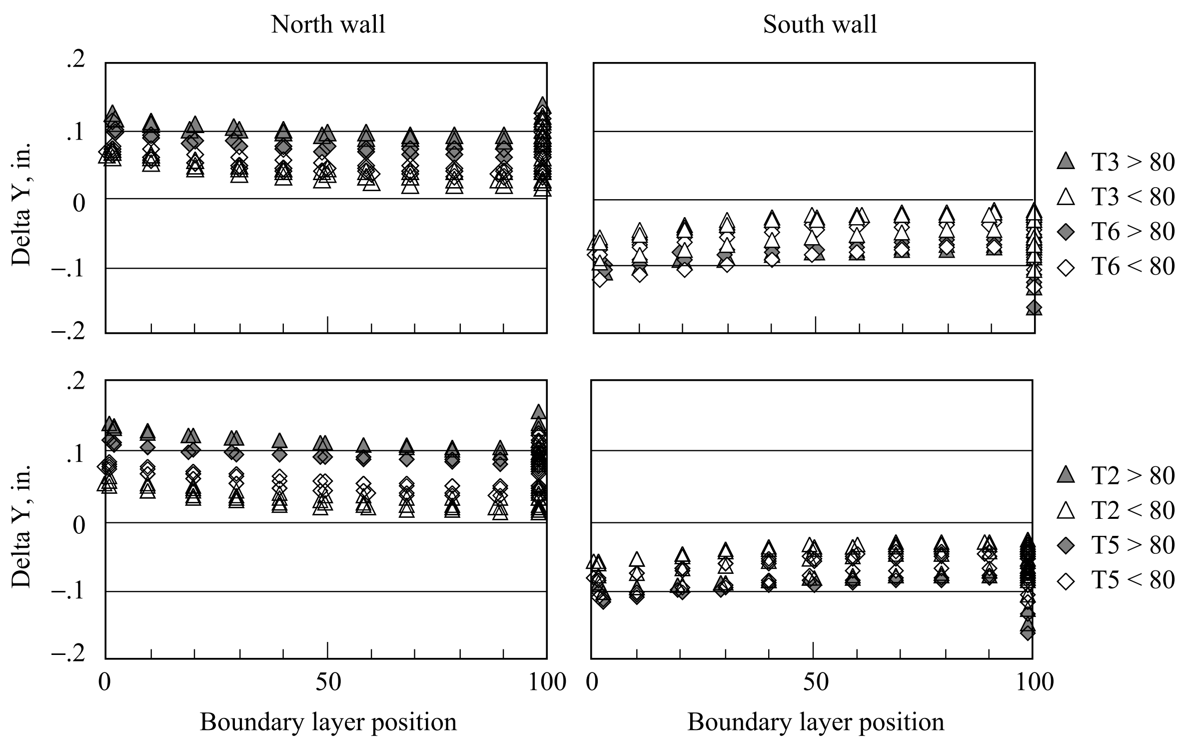

Figure 11. Boundary layer effects on midsection.

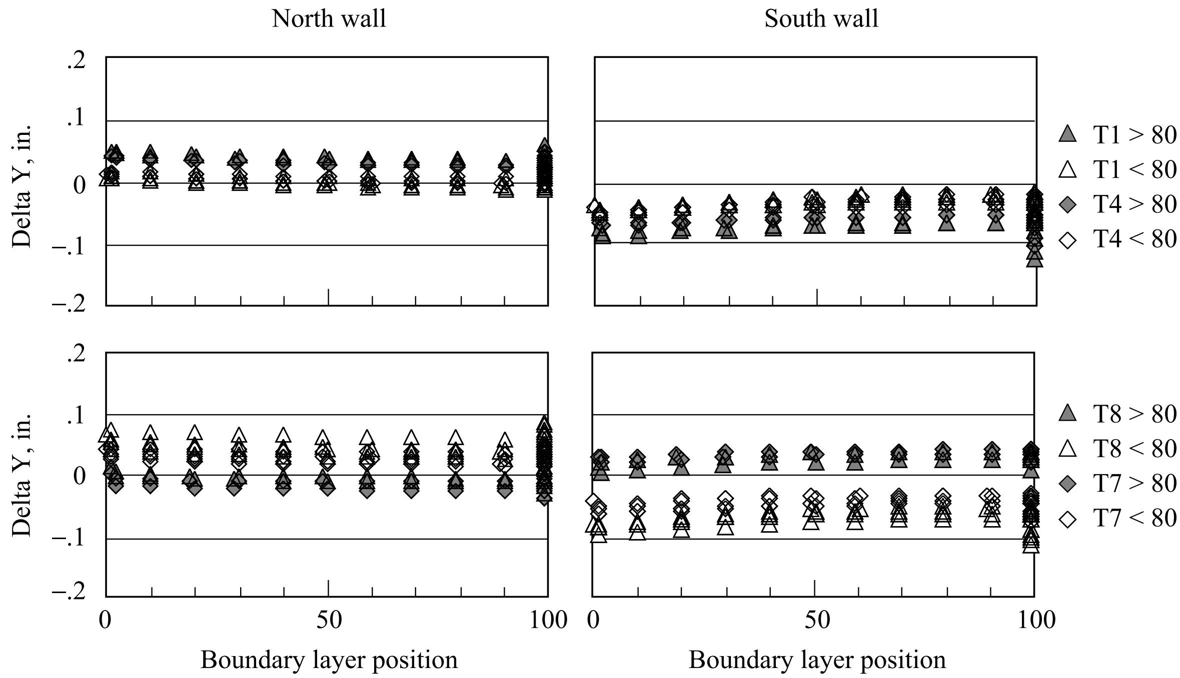

Figure 12. Boundary layer effects on bottom section.

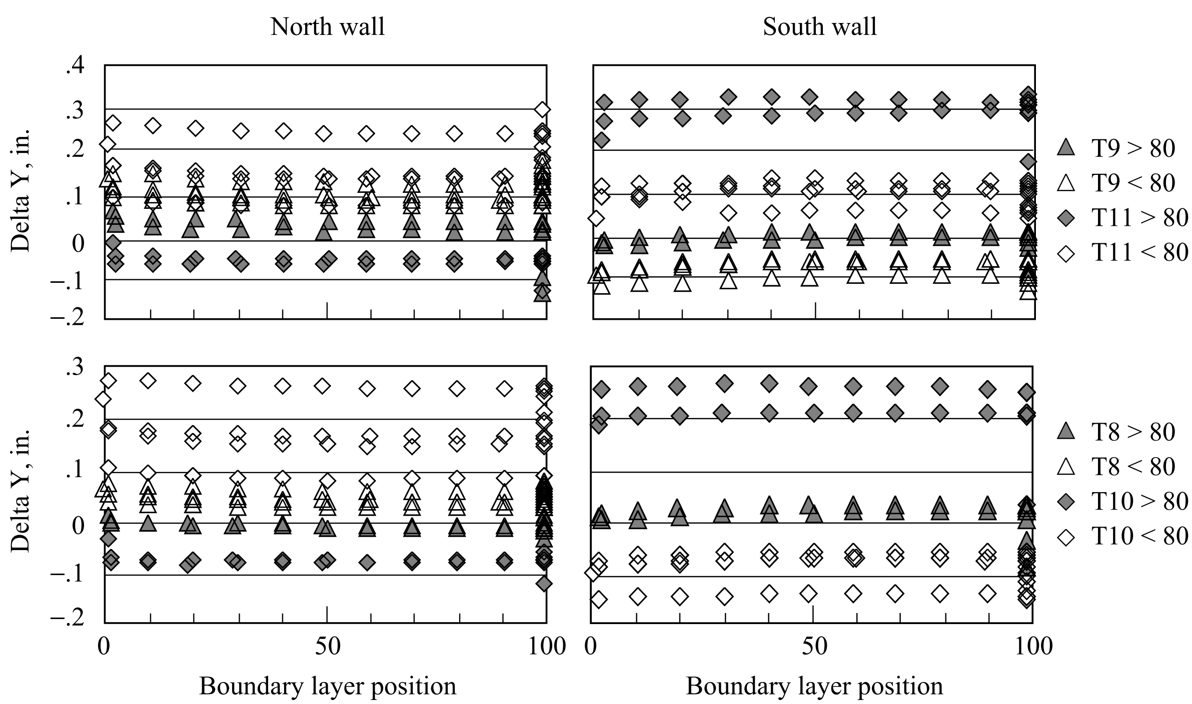

Figure 13. Boundary layer effects on front section.

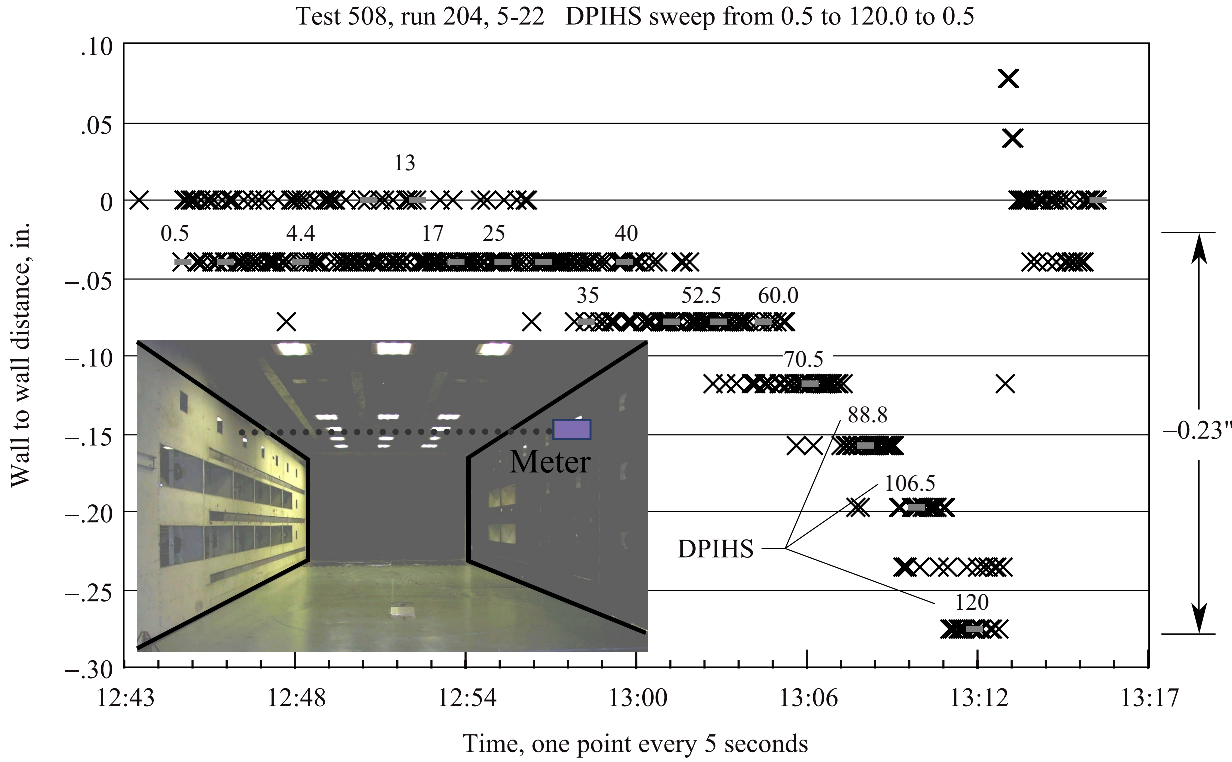

Figure 14. Distancemeter data for test run 204.

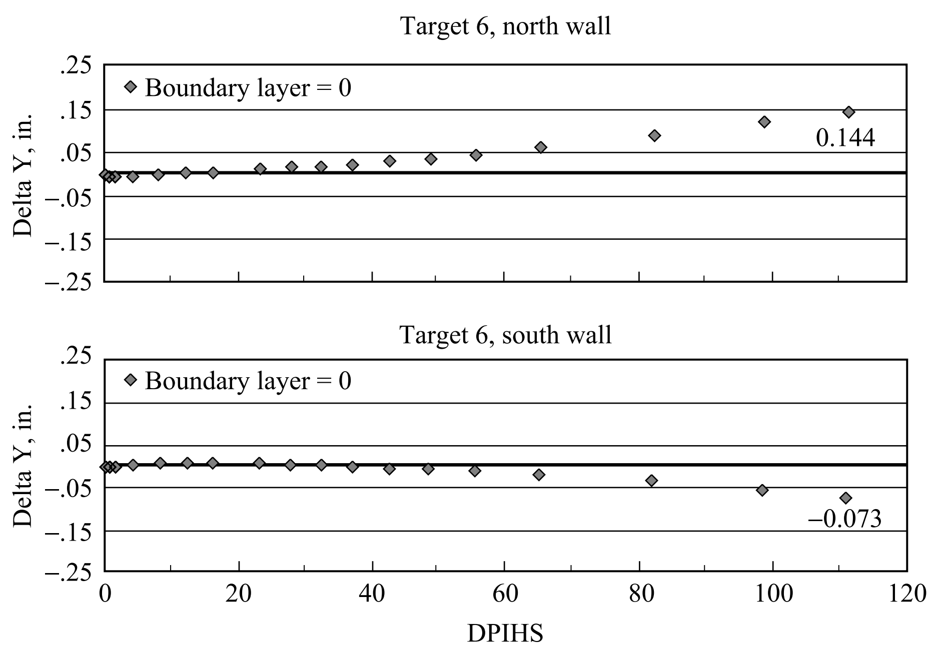

Figure 15. VMS data for target 6 during test run 204.

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14. ABSTRACT

The test section walls of the NASA Langley Research Center 14- by 22-Foot Subsonic Tunnel are known to move under thermal and pressure loads. Videogrammetry was used to measure wall motion during the summer of 2002. In addition, a laser distancemeter was used to measure the relative distance between the test section walls at a single point. Distancemeter and videogrammetry results were consistent. Data were analyzed as a function of temperature and pressure to determine their effects on wall motion. Data were collected between 50 and 100 ºF, 0 and 0.315 Mach, and dynamic pressures of 0 and 120 psf. The overall motion of each wall was found to be less than 0.25 in. and less than facility personnel anticipated. The results show how motion depends on the temperature and pressure inside the test section as well as the position of the boundary layer vane. The repeatability of the measurements was ±0.06 in. This report describes the methods used to record the motion of the test section walls and the results of the data analysis. Future facility plans include the development of a suitable wall restraint system and the determination of the effects of the wall motion on tunnel calibration.

15. SUBJECT TERMS
Videogrammetry; Test section walls; Thermal load; Pressure load

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